FES Joint Facilities Research Milestone 2010

<u>Annual Target:</u> Conduct experiments on major fusion facilities to improve understanding of the heat transport in the tokamak scrape-off layer (SOL) plasma, strengthening the basis for projecting divertor conditions in ITER. The divertor heat flux profiles and plasma characteristics in the tokamak scrape-off layer in multiple devices to investigate the underlying thermal transport processes. The unique characteristics of C-Mod, DIII-D, and NSTX will enable collection of data over a broad range of SOL and divertor parameters (e.g., collisionality ν^*, beta β, parallel heat flux $q_{||}$, and divertor geometry). Coordinated experiments using common analysis methods will generate a data set that will be compared with theory and simulation.

<u>Quarter 1 Milestone</u>

Develop a preliminary research plan coordinated among the three facilities, in order to accomplish the required experiments measuring scrape-off layer characteristics and divertor heat flux, towards the goal of understanding divertor conditions projected for ITER.

<u>Completion of 1st Quarter Milestone</u>

The targeted goal for the first quarter was achieved, as documented in the remainder of this report. A preliminary research plan for individual and coordinated experiments among the three facilities has been developed. In preparation for execution of the research plan, diagnostic capabilities at all three facilities have been significantly enhanced and analyses of past and recently obtained data have been performed to identify gaps in the data sets and to plan for required run time. The principal focus of the research plan at each facility is to obtain an accurate set of divertor heat flux and plasma boundary layer profile measurements over the (wide) available range of externally controlled engineering parameters. In conjunction, a set of coordinated experiments among the three facilities will be performed, centered about matching dimensionless plasma physics parameters in the boundary layer region. These latter experiments will allow the individual data sets to be joined together and compared directly over parameter ranges in which they overlap. Divertor target heat flux data will be analyzed using a common 2-D thermal analysis tool that computes surface heat flux from calibrated temperature measurements. It is important to note that C-Mod operates with refractory metal divertor targets (Mo and W) in a "closed" divertor shape with a near vertical outer target. The DIII-D and NSTX divertors are operated in "open" geometries. The DIII-D targets are horizontal ATJ graphite tiles, while the NSTX targets are horizontal lithium-coated ATJ graphite tiles. Additionally, the Liquid Lithium Divertor (LLD) has just been installed in NSTX, so that part of its divertor target will now be liquid Li. While the differences in the three machines' divertor geometries and materials are not expected to affect the parallel heat conduction physics, they could affect the details of how the divertor heat flux is "mapped" to the midplane, as well as the divertor detachment physics and the complexity of the IR emission measurements. The progress at each facility is described below, followed by a brief description of the coordinated experiments

<u>Alcator C-Mod research preparations</u>

In the Alcator C-Mod, installation of new diagnostic systems to measure tile temperatures and plasma characteristics at the plasma facing surfaces, as well as experimental planning, has been achieved. On the diagnostic side, a fast time response infrared camera was installed to measure the surface temperature and heat flux, and divertor bolometry to measure the radiated power profile was upgraded. In addition, a range of new probes to measure tile temperatures and plasma characteristics were installed: 14 calorimeter probes, 10 surface temperature probes, 10 tile thermocouples, and 10 Langmuir probes were commissioned.

On the experiment planning side, a plan to measure the heat flux profiles and plasma characteristics was developed into a full experimental proposal. The focus of this part of the plan is dedicated to measuring heat flux and plasma profiles during plasma current (I_p) and heating power (P_{heat}) scans in H-mode discharges in several shapes: a lower-single null divertor and a double-null divertor. A range of toroidal fields (B_t) will also be investigated by using different ICRF heating scenarios, including H-minority fundamental and second harmonic frequencies or He-3 minority heating. These experiments will be augmented with heat flux measurements in L-mode and ohmic plasmas. Several of the H-mode experiments will be aimed at a dimensionless identity experiment with the DIII-D device as described below.

DIII-D research preparations

A fast time-response infrared camera was recently commissioned in DIII-D, along with refurbishing of edge reciprocating probes to measure plasma characteristics in the scrape-off layer. The plan for experiments in DIII-D includes 1) measurements of the scrape-off layer profiles at multiple poloidal locations by using both lower single-null and upper single-null shapes, each with the ion grad-B drift toward the active X-point; 2) additional heat flux scaling experiments as a function of P_{heat} magnitude and method (i.e. neutral beam heating vs. electron cyclotron heating); and 3) experiments aimed at a dimensionless identity experiment with Alcator C-Mod and an aspect ratio scan comparison with NSTX, as described in the coordinated experiment section.

NSTX research preparations

A new fast time-response infrared camera was recently commissioned in NSTX, and a new set of high spatial resolution Langmuir probes and divertor bolometry is being commissioned and will contribute to new measurements. Analysis from NSTX (and previous DIII-D and JET publications) has highlighted a strong inverse dependence of the heat flux width on I_p. Thus, a new set of experiments is being planned to extend the I_p range to the highest possible values within NSTX, to see if the trend continues. In addition, separate B_t scans are planned, to determine the role of the safety factor in the I_p dependence of the heat flux width described above. Also the role of shape (single-null vs. double-null) will be documented. Finally a set of experiments is planned, as an aspect ratio scan comparison with DIII-D as described below.

Coordinated experiments

The coordinated experiments are based on matching plasma physics dimensionless quantities ν^*, β, and normalized ion gyroradius ρ^* in the plasma edge region. A true identity experiment also matches scaled plasma equilibrium shapes, e.g. elongation κ, triangularity δ, edge safety factor q_{95}, and inverse aspect ratio ε=a/R. A true identity experiment between C-Mod and DIII-D is planned since the aspect ratio can be matched, as achieved previously in a pedestal similarity experiment [D.A. Mossessian et. al., *Physics of Plasmas* **10** (2003) 689]. The basic idea here is to match these dimensionless parameters at the magnetic separatrix, and possibly at the top of the pedestal, to determine if the SOL profiles and scale lengths also match. Table 1 shows the common shape parameters, as well as the scaling of the dimensionless parameters with minor radius. It should also be possible to match these parameters for several pairings of ν^* and β at constant ρ^*. Then scans about these points will allow for dimensionless parameters scans within each machine. In addition, comparisons between DIII-D and NSTX (at the same minor radius, κ and δ) will provide an aspect ratio scan, provided ρ^* can be matched by extending DIII-D discharges to low B_t as accomplished in a previous pedestal scaling experiment [R. Maingi et. al., Proc. 21st Fusion Energy Conference, Chengdu, China, Oct. 16-21, 2006, paper IT/P1-12].

Table 1 – Equilibrium shape parameters and scaled plasma conditions.

ε	0.28
κ	1.64
δ – *upper*	0.32
δ – *lower*	0.52
q_{95}	3.5

	C-Mod	DIII-D	scaling
R (m)	0.7	1.75	~a
a (m)	0.22	0.55	~a
B_T (tesla)	5.4	1.7	$\sim a^{-5/4}$
I_p (tesla)	1.08	0.86	$\sim a^{-1/4}$
n_e -ped	3×10^{20} m^{-3}	5×10^{19} m^{-3}	$\sim a^{-2}$
T_e -ped	600 eV	380 eV	$\sim a^{-1/2}$